A noise that cannot be eliminated by averaging longer:

1/f noise in semiconductor devices

Spectral Intensity Function

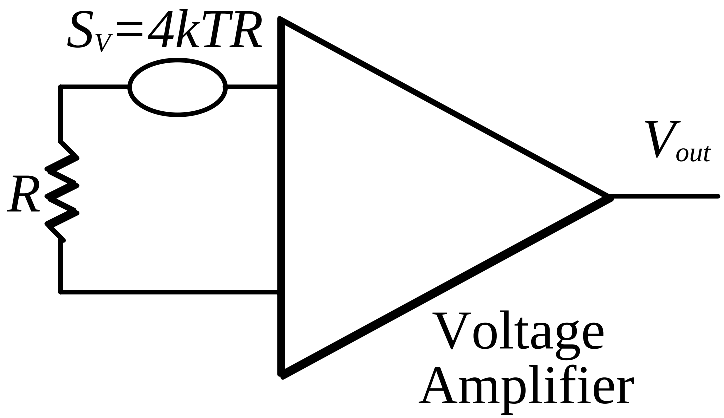
To describe noise in devices, we will use the spectral intensity function which is the Fourier transform of the autocorrelation function. $\langle V(t)V(t-\tau)\rangle_{\text{avg}}$

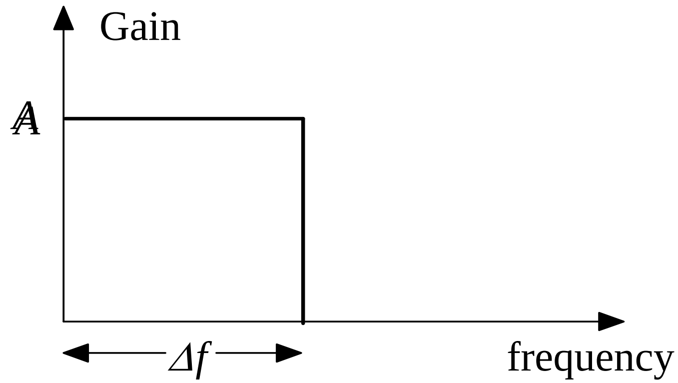
$$S_V(f) = 4\int_0^\infty \langle V(t)V(t-\tau)\rangle_{\text{avg}} \cos(2\pi f\tau)\mathrm{d}\tau$$

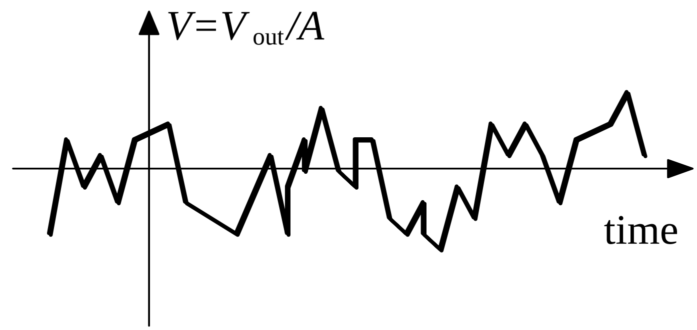
The unit of $S_V(f)$ is Volt^2/Hz

$$\langle V(t)V(t-\tau)\rangle_{\text{avg}} = \int_0^\infty S_V(f)\cos(2\pi f\tau)\mathrm{d}f$$

Thermal Noise







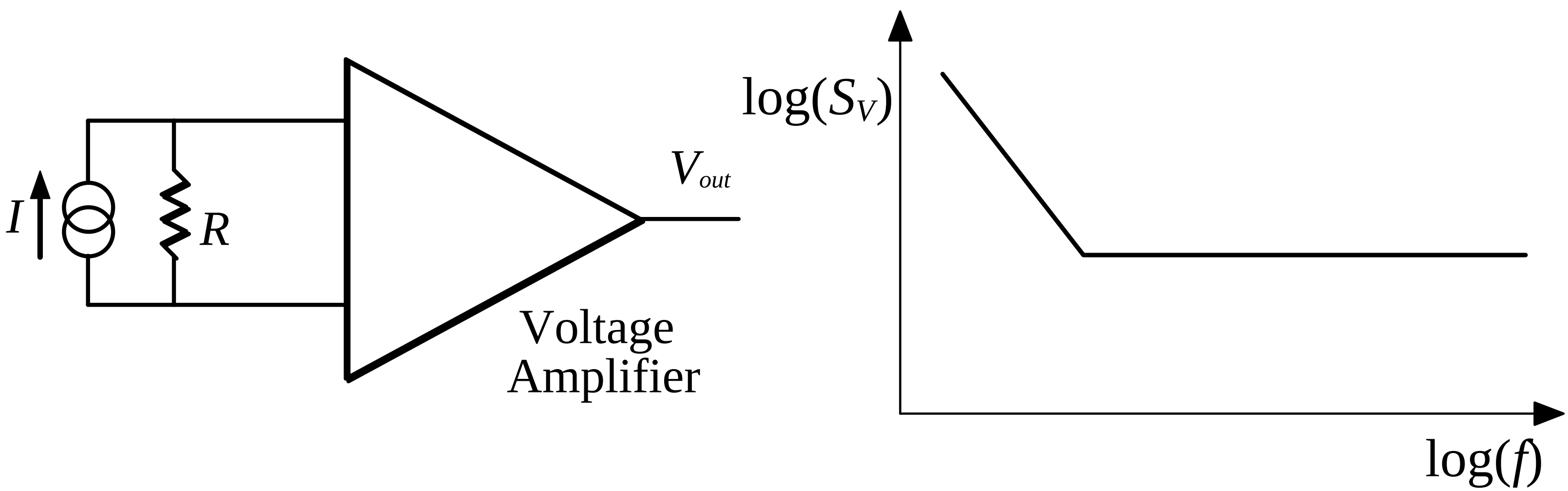
$$\langle V(t)V(t-\tau)\rangle_{\text{avg}} = \int_0^{\infty} S_V(f)\cos(2\pi f\tau)\,\mathrm{d}f$$

$$\langle V(t)V(t)\rangle_{\text{avg}} = \int_0^{\infty} S_V(f)\,\mathrm{d}f = \int_0^{\Delta f} 4kTR\,\mathrm{d}f$$

$$V_{rms} = \sqrt{4kTR\Delta f}$$

1/f Noise

When biased, a resistor made out of a semiconductor typically exhibits additional low frequency noise known as 1/f noise.



$$\langle V(t)V(t)\rangle_{\text{avg}} = \int_0^\infty S_V(f)\,\mathrm{d}f \approx \int_{f_\varepsilon}^{\Delta f} (4kTR + A/f)\,\mathrm{d}f$$

$$V_{rms} = \sqrt{(4kTR\Delta f + A\ln(\Delta f / f_\varepsilon)}$$

Important Experimental Facts About 1/f Noise

- If measured carefully, all semiconductors exhibit some sort of intrinsic 1/f noise.

- Metal resistors do not exhibit 1/f noise

- .The integral of $S_V(f)$ can have a logarithmic divergence (measured at frequencies down to μHz)

- Bigger semiconductor devices have smaller 1/f noise (Hooge's Law)

- In many devices, the low frequency noise deviates from the 1/f spectrum (α=0.7-1.3)

- The amplitude of 1/f noise scales quadratically with the bias current.

$$S_V(f) = \frac{A}{f^{\alpha}} \langle V \rangle^2$$

Resistance Fluctuations

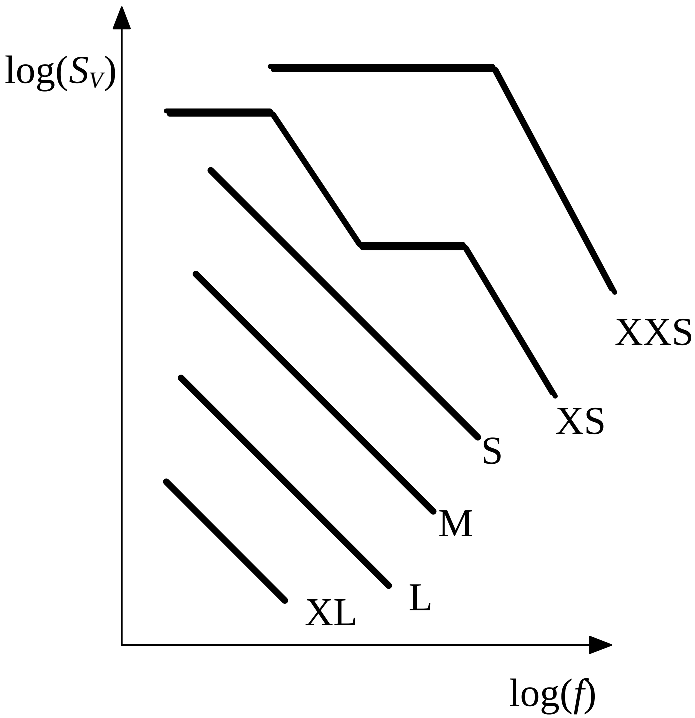
1/f noise is an equilibrium noise caused by resistance fluctuations.

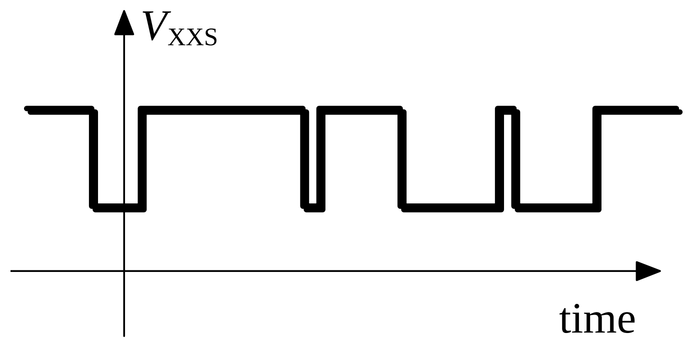
$$\frac{S_V(f)}{\langle V\rangle^2} = \frac{A}{f^{\alpha}} = \frac{S_{S_v}(f)}{\langle S_v\rangle^2} = \frac{S_R(f)}{\langle R\rangle^2}$$

$$R = \frac{L}{ne\mu \cdot \mathrm{Area}}$$

Typically, in a semiconductor device 1/f noise is caused by either mobility or carrier density fluctuations.

Random Telegraph Noise (Popcorn Noise)





$$\langle V(t)V(t-\tau)\rangle_{avg} \propto \exp(-\tau / t_d)$$

$$S_V(f) \propto \frac{1}{1+(2\pi f t_d)^2}$$

1/f noise in a macroscopic device is caused by a superposition of many independent events each with a Lorentzian spectra.